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This study determined the effectiveness of living temporarily at a moderate altitude ("staging") of 2200 m on TT performance of sea-level residents (SLR) during subsequent exposure to 4300 m. Ten healthy men (mean ± SE: 21 ± 1 yrs) were tested on a cycle ergometer during a 720 kJ maximum effort TT at SL, and again beginning within 3 hrs of exposure to 4300 m (459 Torr) before (preSTG) and after (postSTG) staging for 6 d at 2200 m (601 Torr). Arterial oxygen saturation (SaO2) was measured every 5 min during exercise. TT duration increased ($P<0.01$) from 73 ± 6 min at SL to 111 ± 6 min at preSTG and to 92 ± 7 min at postSTG, and was 17 ± 6% (19 ± 6 min) faster postSTG than preSTG ($P<0.01$). TT performance of each man improved preSTG to postSTG, with the improvement being directly related to exercise SaO2 ($R = 0.88$, $P<0.03$). It was concluded that 6 days of staging attenuated the impairment in prolonged TT performance of SLR rapidly exposed to 4300 m. The close association between improved TT performance and higher exercise SaO2 suggest the major contributing factor was increased ventilation.

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# USARIEM TECHNICAL REPORT T08-04

## LIVING FOR SIX DAYS AT 2200 M IMPROVES TIME-TRIAL PERFORMANCE OF SEA-LEVEL RESIDENTS EXPOSED TO 4300 M

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## BACKGROUND

A major collaborative research project titled *"Determining the effectiveness of short-term staging at 2200 m on physical and cognitive performances, and acute mountain sickness at 4300 m"* was funded by the US Army Medical Research Materiel Command ATO IV.MD.2006.01. Participating were scientists from the United States Army Research Institute of Environmental Medicine (Natick, MA), Air Force Academy (Colorado Springs, CO), Air Force Research Laboratory (Brooks City Base, TX), The College of William and Mary (Williamsburg, VA), Oklahoma State University (Tulsa, OK), Kent State University (Kent, OH), and the University of Colorado (Colorado Springs and Denver, CO).

The current project was the third of three high altitude "Pikes Peak" studies that were independently conducted, yet deliberately closely linked to the first two studies by standardization of procedures. The ONLY major difference planned among the three projects was the altitude acclimatization status of the volunteers prior to their deployment to 4300 m. In the first two projects (already completed), unacclimatized sea-level residents (SLR, 150 m) and acclimatized moderate altitude residents (MAR, 2200 m) were rapidly and directly deployed to 4300 m from their resident altitudes. In the current project, unacclimatized SLR were first "staged" at a moderate altitude of 2200 m for 6 days prior to being deployed to 4300 m. The staging elevation was chosen to be similar to that of various Forward Operating Bases being used currently in Afghanistan (e.g., Orgun-E, 2133 m and Shkin, 2378 m).

The overall objective of the current project was to determine, in previously unacclimatized SLR, the effectiveness of staging in minimizing impairments in physical and cognitive performances, and reducing acute mountain sickness incidence and severity during subsequent high altitude exposure. The data presented here will be focused on the effects of staging at moderate altitude on prolonged endurance performance of SLR during exposure to 4300 m. The results from the current study also will be compared to those of our previous two Pikes Peak studies to determine the relative effectiveness of short-term staging to no prior altitude acclimatization and to full, moderate altitude acclimatization, respectively.

## EXECUTIVE SUMMARY

The magnitude of the initial impairment in prolonged time-trial (TT) performance that occurs when sea-level residents (SLR) ascend rapidly to high altitude (e.g., 4300 m) is attenuated with acclimatization to the same elevation. Whether adaptations acquired from living temporarily at a moderate altitude (“staging”) just prior to the high altitude exposure will benefit TT performance at high altitude is less certain. This study determined the effectiveness of staging at 2200 m on TT performance of SLR during subsequent exposure to 4300 m. Ten healthy men (mean ± SE: 21 ± 1 yrs) were tested on a cycle ergometer during a 720 kJ maximum effort TT at SL, and again beginning within 3 hrs of exposure to 4300 m (459 Torr) before (preSTG) and after (postSTG) staging for 6 d at 2200 m (601 Torr). Arterial oxygen saturation ($SaO_2$), heart rate (HR), and ratings of perceived exertion (RPE) were measured every 5 min during exercise. TT duration increased ($P<0.01$) from 73 ± 6 min at SL to 111 ± 6 min at preSTG and to 92 ± 7 min at postSTG, and was 17 ± 6% (19 ± 6 min) faster postSTG than preSTG ($P<0.01$). Despite performing the TT at a higher power output postSTG than preSTG (120 ± 7 vs. 100 ± 10 W, $P<0.01$), RPE was lower (13 ± 1 vs. 16 ± 1, $P<0.01$) and $SaO_2$ tended to be higher (76 ± 1 vs. 74 ± 1%, $P=0.15$). TT performance of each of the10 men improved preSTG to postSTG, with the improvement being directly related to their respective increase in $SaO_2$ during exercise ($R = 0.88$, $P<0.03$). It was concluded that 6 days of staging attenuated the impairment in prolonged TT performance of SLR rapidly exposed to 4300 m. The close association between improved TT performance and higher exercise $SaO_2$ suggest the major contributing factor was increased ventilation.

## INTRODUCTION

The duration of an endurance performance task that requires a fixed amount of work be completed as quickly as possible is progressively lengthened as altitude increases (9; 11; 12). However, acclimatization acquired by living for a period of days to weeks at any given altitude typically improves endurance performance compared to that during earlier exposure (4; 10; 12; 13; 16; 17; 21). For example, for unacclimatized sea-level residents (SLR) ascending directly from sea level to 4300 m, a prolonged 720 kJ cycle time trial (TT) took 43 min longer than at sea level to complete on the third day of exposure, but improved by 35% to only 28 min longer by the $10^{th}$ day (9).

Full acclimatization acquired at a moderate altitude also can dramatically improve 720 kJ cycle TT performance during subsequent exposure to a higher elevation. Moderate altitude residents (MAR) who had lived for nearly 2 years at 2200 m performed 50% to 70% better compared to SLR during the first few days of exposure to 4300 m (11). The superior TT performance of the MAR relative to SLR (9) provided an indication of what is likely the maximum benefit that can be derived from acclimatizing to a moderate altitude of 2200 m on subsequent rapid exposure to 4300 m.

“Staging” or temporarily residing at a moderate altitude prior to ascending to a higher elevation has long been used as a practical acclimatization strategy, especially for previously unacclimatized SLR (5; 7; 8; 14; 15; 19; 22; 23; 25; 29). In general, an ideal staging altitude is that which is high enough to initiate at least some compensatory physiological adjustments, but not so high that the adverse consequences such as acute mountain sickness (AMS) develop (19). The basic premise is that the short-term acclimatization acquired during staging “carries over” and helps to avoid severe AMS that is often associated with direct, rapid ascent to higher altitudes (7; 15; 25; 29). In fact, it has been the decrease in the incidence or severity of AMS symptoms that has typically served as the primary means to assess whether the time spent at a given staging altitude successfully prepared individuals for their subsequent high-altitude exposure (7; 23).

Perhaps because staging at moderate altitudes has so frequently been successful in attenuating AMS at higher elevations, it is often presumed that it must also benefit other markers of acclimatization, such as improved endurance performance during the same period of time (23). However, to our knowledge, this presumption has not been scientifically evaluated.

The first objective of this study, therefore, was to assess in previously unacclimatized SLR, the effectiveness of acclimatization resulting from 6 days of staging at a moderate altitude of 2200 m on prolonged TT performance during subsequent, initial exposure to 4300 m. Identical standardized procedures to assess 720 kJ cycle TT performances that were used in the current study were also used in our previous studies of SLR (9) and MAR (11). Thus, a second objective was to make comparisons of the effectiveness of staging at a moderate altitude on TT performance during initial exposure to 4300 m relative to no prior altitude acclimatization (i.e., SLR, (9)) and to full, moderate altitude acclimatization (i.e., MAR, (11)).

# METHODS

## VOLUNTEERS

Ten men who were active duty military personnel assigned to the U.S. Army Natick Soldier Center volunteered to participate. All had been living at low altitudes (<1000 m) for at least 3 months prior to the start of the study. The age, height and weight of the volunteers were (mean ± SE): 21 ± 1 yr, 177 ± 3 cm, and 78 ± 4 kg, respectively. In addition to participating in Army physical training for 3-4 d/week (e.g., running, calisthenics, backpacking), the men reported regularly participating for at least 1 h/day for 22.7 ± 5 d/month in activities such as basketball (n=6), weightlifting (n=6), football (n=5), baseball (n=5), and competitive skateboarding (n=1). Eight were nonsmokers and two smoked less than 10 cigarettes/day.

All provided verbal and written consents after being fully informed of the nature of the study and its possible risks and benefits. The study was approved by the institutional review boards of the US Army Research Institute of Environmental Medicine (USARIEM), US Army Medical Research and Materiel Command, Human Research Protection Office, The Air Force Academy (AFA), Brooks City Base, and The College of William and Mary. All investigators adhered to policies for protection of human volunteers as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 45 CFR Part 46.

## OVERVIEW: TESTING PHASES AND FACILITIES

This study was organized into four distinct phases at three different test facilities over a period of approximately 13 weeks in the following order: [1] a baseline assessment phase at USARIEM, Natick, MA, [2] a moderate altitude acclimatization or “staging” phase at the Air Force Academy (AFA, Colorado Springs, CO), [3] a high-altitude phase at the summit of Pikes Peak (Colorado Springs, CO), and [4] a post-Pikes Peak phase at USARIEM. The same equipment that was used at USARIEM was used at the AFA and on the summit of Pikes Peak.

The baseline assessment phase was conducted in the Hypobaric Chamber (HC) and in adjacent laboratory rooms at USARIEM over a period of 4 weeks for each volunteer. The HC consists of large (200 sq ft) and small (108 sq ft) environmentally controlled (altitude, temperature and humidity) study chambers that are connected by a common airlock (36 sq ft) having bathroom facilities.

Resting metabolic and blood measurements, AMS, peak oxygen uptake ($\dot{V}_{O_2 peak}$), and long endurance performance procedures occurred on multiple occasions during the baseline assessment phase at sea level (SL, $P_b$ =~760 Torr, 50 m equivalent) and during acute hypobaric chamber exposures (HC, $P_b$ =459 Torr or 4056 m equivalent[1]) (see Table

[1] 4300 m is the terrestrial elevation of the summit of Pikes Peak, CO, with 446 Torr being the expected barometric pressure ($P_b$). However, it was anticipated from previous experience that the true $P_b$ in the laboratory on the summit would range from 458 to 462 Torr during the planned summertime data collection for a true $P_b$ equivalent of ~4056 m. To be consistent in terminology to that used in

1 and Procedures below). Decompression from 760 Torr to 459 Torr took ~10 min. At USARIEM, cycle maintenance training was conducted under SL conditions only. During all assessments at SL or in hypobaria, the HC and other testing areas were maintained at a temperature of 21 ± 2$^{o}$C and relative humidity of 45 ± 5%.

After all assessments and training were completed at USARIEM, the volunteers were flown non-stop via commercial airline to Colorado in about 6 hrs (arrival time 2 pm) to participate in the moderate altitude staging phase that was conducted over a 6-day period in the Human Performance Laboratory (HPL) and its surrounding rooms (~2200 m, ~601 Torr) at the AFA. To facilitate study needs, the volunteers traveled in groups of two on consecutive days. Temperatures and relative humidity were similar to those of USARIEM. Cycle maintenance training was performed within the HPL on days 1, 2, 4-6. In addition, all volunteers participated in two to four supervised hikes (<3 hr) on trails located around the AFA base.

At 0600 h of the 7$^{th}$ day at the AFA, the volunteers were driven (~1.5 hrs) to the summit of Pikes Peak ($P_b$ range: 458 to 462 Torr, 4300 m) to begin the third phase of the study. The timing and sequence of the resting and exercise assessments were identical to those used during the first several hours in the HC during the baseline phase at USARIEM. Indoor temperature was 20 ± 3$^{o}$C, with relative humidity <40%. (It should be noted that the volunteers lived at the summit of Pikes Peak for 4 additional days and participated in other substudies prior to being transported back to USARIEM. On each of these days, the volunteers cycled and went hiking at high altitude [weather permitting]. The data collected beyond the completion of the long endurance performance assessment on the 1$^{st}$ day will be reported elsewhere.)

The last phase was conducted at SL within 2 days of the volunteers returning to USARIEM. Only a single cycle maintenance training bout was performed.

The volunteers were told not to perform any nonstudy-related leg exercise for 24 hr before each test session. Volunteers were allowed to eat *ad libitum* throughout the entire study, except when they were provided with two commercially available energy bars and fruit juice (food composition = 510 kcal, 14 gm fat, 65 gm carbohydrate, 32 gm protein) at 3 hrs prior to the beginning of each of the long endurance performance assessments.

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previous studies, the altitude at the summit of Pikes Peak will also be referred to here as 4300 m. The $P_b$ used during testing in the Hypobaric Chamber at USARIEM was 459 Torr (4056 m).

**Table 1. Testing Procedure and Scheduling Overview**

| PROCEDURES: | USARIEM (SL) | USARIEM (HC1) | USARIEM (HC2) | AFA | PP | USARIEM (SL) |
|---|---|---|---|---|---|---|
| Resting Ventilatory | X | | X | X | X | |
| Resting Blood | X | | X | X | X | |
| AMS Assessment | X | | X | X | X | |
| $\dot{V}_{O_2 peak}$ | X | X | | | | |
| Maintenance Cycling | X | | | X | | X |
| Long Endurance Performance | X | | X | | X | |
| Exercise HR, $SaO_2$, RPE | X | X | X | X | X | X |

SL = Sea level; HC1 = hypobaric exposure <1 hr; HC2 = hypobaric exposure, all testing completed <6 hrs; AFA = Air Force Academy; PP = Pikes Peak; AMS = acute mountain sickness; $\dot{V}_{O_2 peak}$ = peak oxygen uptake; HR = heart rate; $SaO_2$ = arterial oxygen saturation; RPE = ratings of perceived exertion.

## PROCEDURES

### PEAK OXYGEN UPTAKE

An incremental, progressive exercise bout to volitional exhaustion on an electromagnetically braked cycle ergometer (model: Excalibur, Lode BV, Groningen, The Netherlands) was used to assess $\dot{V}_{O_2 peak}$. Data from the $\dot{V}_{O_2 peak}$ tests were subsequently used to determine the steady-state power outputs during cycle maintenance training and the long endurance performance assessment, and to estimate the energy costs of the self-selected power outputs during the time-trial portion of the long endurance performance assessments. Three $\dot{V}_{O_2 peak}$ tests were conducted on separate days during the baseline assessment phase at USARIEM: two at SL (one for practice) and during acute (<1 hr) hypobaric exposure.

Measurements of $O_2$ uptake were obtained throughout each $\dot{V}_{O_2 peak}$ test using a calibrated metabolic cart (True Max 2400, Parvo Medics, Sandy, UT). The volunteer began pedaling at 60 to 100 rpm at 50 watts for a 3 min warm up. The power output was then increased stepwise every 2 min at 50 w, 100 w, 130 w, and 160 w. Then starting at 175 w, the power output was increased by 15 w every minute until $O_2$ uptake failed to increase, or the volunteer could not continue despite strong verbal encouragement.

### CYCLE MAINTENANCE TRAINING

Cycle maintenance training was conducted using electromagnetically braked cycle ergometers (model: Corival, Lode BV, Groningen, The Netherlands) four times during USARIEM baseline assessment phase (SL conditions only), five times during the AFA moderate altitude staging phase, and once on return to USARIEM at SL after the Pikes Peak phase. Each training session consisted of 5 min of warm up at 50 w, 30 min of steady-state exercise at an individually determined fixed power output and, after a 5 min break, a 180 kJ time trial (except on the last day at the AFA to allow adequate rest prior to cycling at PP). The power output that was used during the 30 min steady-state portion of cycle maintenance training was identical to that used for 20 min during 45% $\dot{V}_{O_2peak}$ at SL during the long endurance performance assessment.

Having the volunteers perform 10 sessions of cycle maintenance training periodically throughout the 13 week study allowed them to maintain familiarity with the cycling procedures and time-trial pacing strategies. In addition, having the volunteers use the identical fixed power output during steady-state exercise for each of the training sessions at SL and during moderate altitude staging conditions allowed for the frequent monitoring of potential physiological adjustments resulting from staging. It was also considered that using the same power output that represented only 45% of SL $VO_{2peak}$ and a relatively short-time trial segment (~15 min) would allow the normally active volunteers to maintain, but not increase, their fitness status throughout the study.

## RESTING END-TIDAL $CO_2$ AND $O_2$, ARTERIAL OXYGEN SATURATION, AND HEART RATE

Measures of resting partial pressures of end-tidal carbon dioxide ($P_{ET}CO_2$) and oxygen ($P_{ET}O_2$), arterial oxygen saturation ($SaO_2$), and HR were conducted with the volunteers awake, fasting, and relaxed for at least 2 hrs. During these tests, the volunteers were in a semi-recumbent position for 15-20 min while connected to a breathing circuit by a rubber mouthpiece and nose clip, and to a finger pulse oximeter unit (Model 8600, Nonin Medical, Inc., Plymouth, MN) to record $SaO_2$ and HR. $P_{ET}CO_2$ and $P_{ET}O_2$ were determined using a metabolic cart (Vmax 229 Sensormedics Inc, Yorba Linda, CA). $P_{ET}CO_2$, $P_{ET}O_2$, and $SaO_2$ were determined in the morning twice at SL and once during acute (<2 hrs) hypobaric exposure during USARIEM baseline phase, and within the first 2 hrs of arrival on the summit of Pikes Peak. All resting measurements were obtained on the same days and just prior to the long endurance performance assessments being conducted. These measures were performed to monitor acclimatization status before and after 6 days of staging at moderate altitude.

## RESTING CAPILLARY CARBON DIOXIDE, AND VENOUS HEMOGLOBIN, HEMATOCRIT, AND GLUCOSE

On most days that the resting measures of $P_{ET}CO_2$, $P_{ET}O_2$, $SaO_2$, and HR were determined, arterialized and venous blood samples were obtained. Resting arterialized and venous blood samples were taken at SL and during acute (~2 hrs) hypobaric exposure during USARIEM baseline assessment phase, on the 2nd day of moderate altitude staging at the AFA, and ~2 hrs after arriving at the summit of Pikes Peak. Also, in the mornings of days 4 and 6 at the AFA, arterialized and venous blood samples were obtained, respectively. Arterialization was achieved by warming the hand in 43ºC water for 5 min prior to obtaining a 150 µL fingertip blood sample for the measurement of $P_aCO_2$. Also obtained was a 5 ml venous blood sample from an arm vein for the measurement of hemoglobin (Hb), hematcrit (Hct) and glucose. The arterialized and venous samples were analyzed immediately in duplicate using an iStat portable clinical analyzer (Abbott Diagnostics, Abbott Park, IL). Resting $P_aCO_2$, Hb, and Hct were used to monitor acclimatization status before, during and after 6 days of moderate altitude staging, and blood glucose was used to confirm that the volunteers began each long endurance performance assessment in a similar post-prandial state.

## ACUTE MOUNTAIN SICKNESS

Acute mountain sickness (AMS) was determined from information gathered using a subset of the Environmental Symptoms Questionnaire (ESQ) and the Lake Louise AMS Scoring System (LLS) administered using a personal digital assistant (PDA; HP model: iPAQ). The ESQ used in this study was a shortened version (2) of the self-reported, 68-question inventory used to document symptoms induced by altitude (27). A weighted average of scores from 9 symptoms (headache, lightheaded, dizzy, etc.) designated "AMS-C" was calculated. The weighted scores range from 0 (no symptoms) to 5 (severe symptoms). AMS-C scores equal to or greater than 0.7 indicate the presence of AMS. The LLS consists of a 6 question, self-reported assessment of AMS symptoms (24). Total LLS scores that include headache and are ≥3 (range: 0 to 18) are diagnostic of AMS. The questionnaires were administered while resting in the mornings at SL (for practice and baseline measures) and at the AFA to determine incidence and severity of AMS during moderate altitude acclimatization. They were also administered within 1 hr prior to the long endurance performance assessment during HC and Pikes Peak to determine the incidence and severity of sickness.

## LONG ENDURANCE PERFORMANCE

Long endurance performance was determined using an electromagnetically braked cycle ergometer (model: Excalibur, Lode BV, Groningen, The Netherlands) three times during USARIEM baseline assessment phase (two at SL and one beginning within 3 hrs of HC), and once beginning within 3 hrs of arriving at the summit of Pikes Peak, as previously described. Each long endurance performance assessment consisted of two major segments: [1] 5-min of warm up at 50 watts, then steady-state exercise for 20 min at 45 ± 5% (low intensity) and then 20 min at 65 ± 5% (high intensity) of their altitude-specific $\dot{V}_{O_2 peak}$, and [2] a 720 kJ maximum effort time trial. For all tests and throughout the duration of each test, water was provided *ad libitum.* These procedures have previously been described in detail (9).

Briefly, in the last 5 to 10 min at the end of each 20 min steady-state exercise session, $O_2$ uptake was measured using a metabolic cart (True Max 2400, Parvo Medics, Sandy, UT). The power outputs used for the 45% and 65% steady-state exercise bouts in the HC during the baseline phase at USARIEM and on the summit of Pikes Peak were identical. This portion of the procedure allowed for direct and standardized assessment of physiological responses during exercise at SL and high altitude exposure, and to the effects of staging on high altitude exposure at the same metabolic demand.

After a 5 min break, the volunteers were asked to complete the 720 kJ time trial as fast as possible. They were allowed to alter pedaling speed and adjust power output by any watt increment at any time during the time trial. Volunteers were continuously informed of the volume of work performed and remaining; but not time elapsed. The 720 kJ time-trial segment provided the primary outcome variable to determine if acclimatization acquired during moderate altitude staging would improve endurance performance during subsequent exposure to high altitude. The implication being that if sufficient physiological acclimatization occurred at moderate altitude that was beneficial to exercise at high altitude, then time-trial duration would be reduced from HC to PP.

## OTHER MEASURES DURING CYCLE EXERCISE

Heart rate via HR watch (Polar Electro, Woodbury, NY) and $SaO_2$ via noninvasive finger pulse oximetry (Model 8600, Nonin Medical, Inc, Plymouth, MN) were monitored continuously, and ratings of perceived exertion (RPE, 6 to 20 Borg scale (3)) were determined either at the end of every power output during $\dot{V}_{O_2 peak}$ tests or every 5 min during cycle maintenance training and the long endurance performance assessment.

## COMPARISONS TO PREVIOUS STUDIES

Much of the methodology, equipment and staff employed in the present study were identical to two recent investigations by our laboratory (9; 11). By design, the major difference among the three studies was the amount of moderate altitude acclimatization the volunteers of each study received before being exposed to 4300 m. In one study (9), volunteers had no moderate altitude acclimatization; all were unacclimatized SLR taken directly from sea level to 4300 m. The second study (11) used volunteers who had lived at 2200 m for an average of 21 months before being transported to 4300 m. Therefore, the responses of the volunteers in the present study who lived for 6 days at 2200 m were assessed at 4300m relative to those having no prior moderate altitude acclimatization and to those considered to have full moderate altitude acclimatization (4).

## STATISTICS

Analysis of variance with (current study) or without (comparison to previous studies (9; 11)) repeated measures on one (days) or two (days x times) factors was utilized for performance, physiological, and blood values (Statistica v7.1, Statsoft, Tulsa, OK). Paired t-tests also were used on data collected at high altitude before and after staging at moderate altitude (i.e., HC and PP) to assess whether moderate altitude acclimatization altered physiological responses during exposure to 4300 m. Post hoc (Newman-Keuls) were performed when appropriate. Regression analyses were used to determine relationships between physiological measures (e.g., $SaO_2$) and exercise performance (e.g., TT duration). Statistical significance was accepted when $P \leq 0.05$. All values are expressed as means ± SE unless otherwise indicated.

## RESULTS

### $\dot{V}O_{2peak}$

$\dot{V}O_{2peak}$ declined from 3636 ± 215 ml/min at SL to 2693 ± 89 ml/min ($P<0.01$) in the HC. At $\dot{V}O_{2peak}$, there were also declines ($P<0.01$) in $W_{peak}$ (283.0 ± 10 to 233.5 ± 7 W) and $SaO_2$ (97.1 ± 1 to 74.8 ± 2%). In contrast, there was no difference in $HR_{peak}$ (186.2 ± 3 vs. 182.8 ± 3 b/min).

### CYCLE MAINTENANCE TRAINING (Table 2)

#### Steady-State Exercise

Throughout the SL and staging phases, steady-state (SS) power output was maintained for 30 min at 116.0 ± 8 watts or 45% of $W_{peak}$. There were no differences among test days for HR or RPE. For $SaO_2$, values on all staging days were lower than for either SLpre or SLpost. In addition, $SaO_2$ was lower on STG1 (staging, day 1) than for STG2 (day 2) and STG4-6 (days 4-6).

#### Time-Trial Performance

The 180 kJ time trials were performed during the SL and staging phases of the study. There was no change in performance times among testing days. Also listed are the values for HR, $SaO_2$, and RPE that were recorded during the last 5 min of the time trial. Exercise HR did not change over time. $SaO_2$ was lower on each test day of staging compared to SL and was lower on STG1 compared to each of the other staging test days. RPE measured during the staging phase did not differ from SLpre. RPE during the last time trial of the study at SLpost was lower than those of SLpre and STG1.

**Table 2. Steady-State and Time-Trial Exercise Values During Cycle Maintenance Training**

| SS: | SLpre | STG1 | STG2 | STG4 | STG5 | STG6 | SLpost |
|---|---|---|---|---|---|---|---|
| HR (b/min) | 133 ± 6 | 132 ± 5 | 127 ± 6 | 133 ± 4 | 130 ± 5 | 126 ± 5 | 127 ± 5 |
| $SaO_2$ (%) | 96 ± 1 | 89 ± 1*,[a] | 91 ± 1* | 92 ± 1* | 92 ± 1* | 92 ± 1* | 98 ± 1 |
| RPE | 9 ± 1 | 8 ± 1 | 8 ± 1 | 8 ± 1 | 8 ± 1 | 8 ± 1 | 8 ± 1 |
| TT: | | | | | | | |
| TT (min) | 16.0 ± 1 | 14.7 ± 1 | 15.1 ± 1 | 15.8 ± 1 | 16.4 ± 1 | | 16.3 ± 1 |
| HR (b/min) | 176 ± 5 | 173 ± 3 | 175 ± 3 | 172 ± 3 | 167 ± 5 | | 167 ± 5 |
| $SaO_2$ (%) | 96 ± 1 | 88 ± 1*,[a] | 91 ± 1* | 91 ± 1* | 90 ± 1* | | 97 ± 1 |
| RPE | 14 ± 1 | 14 ± 1 | 13 ± 1 | 13 ± 1 | 13 ± 1 | | 12 ± 1[b] |

SS = Steady-state exercise at 45% $VO_{2peak}$; TT = Time trial, 180 kJ; Data in the table are for the 25$^{th}$ min of SS exercise or for the last 5 min of the TT performance, respectively; SLpre and SLpost = cycle maintenance training performed at SL before (pre) and after (post) the staging and Pikes Peak phases; STGx = Day of staging at moderate altitude; *P<0.01 lower than SLpre and SLpost; [a]P<0.05 STG1 lower than all other STG days; TT (min) = time in minutes to complete the TT; [b]P<0.03 from SLpre.

Collectively, the lack of change in TT performance and perception of effort during the cycle maintenance training sessions during the moderate altitude staging phases and in comparison to SLpre indicates that the fitness level of the volunteers was maintained, and not improved while living at the AFA. In contrast, the increases in $SaO_2$ from STG1 to STG2 through STG6 for SS exercise and through STG5 during the TT segment are consistent with moderate altitude acclimatization.

## RESTING END-TIDAL CARBON DIOXIDE AND OXYGEN, ARTERIAL OXYGEN SATURATION, AND HEART RATE

From SL to HC, values for resting $P_{ET}CO_2$ and HR were not changed, while resting $P_{ET}O_2$ and $SaO_2$ were reduced (Table 3). In contrast, from HC to PP, there were decreases in $P_{ET}CO_2$ and HR, and increases in $P_{ET}O_2$ and $SaO_2$. The changes in $P_{ET}CO_2$, $P_{ET}O_2$, and $SaO_2$ indicate that 6 days moderate altitude staging resulted in significant ventilatory acclimatization that was quite evident during initial exposure to Pikes Peak.

**Table 3. Resting Cardio-Respiratory Values at Sea Level, and Before and After Staging**

| | Sea Level | Hypobaric Chamber | Pikes Peak |
|---|---|---|---|
| **$P_{ET}CO_2$** | 39.5 ± 1 | 39.1 ± 1 | 32.8 ± 1*,[a] |
| **$P_{ET}O_2$** | 105.1 ± 2 | 47.7 ± 1* | 50.2 ± 1*,[a] |
| **$SaO_2$** | 97.0 ± 1 | 80.1 ± 1* | 83.1 ± 1*,[a] |
| **HR** | 69.9 ± 2 | 71.6 ± 2 | 65.1 ± 2[b] |

*$P<0.01$ from SL. [a]$P<0.01$ from hypobaric chamber, [b]$P<0.05$ from hypobaric chamber.

## RESTING BLOOD RESULTS (Table 4)

All resting values for $P_aCO_2$ in the HC, on STG2 and STG4, and at PP were lower than at SL. In addition, $P_aCO_2$ at PP was lower compared to the HC and STG2 and STG4. These results are consistent with the $P_{ET}CO_2$ data indicating that there was a considerable ventilatory acclimatization by the time the volunteers arrived at PP. Both Hb and Hct were higher at PP than at SL or HC. Hematocrit at PP was also higher than for STG2. The calculated %PV reduction was higher at PP than in the HC (6). These data indicate that after 6 days of staging at moderate altitude, there was a small, but statistically significant hemoconcentration, consistent with at least partial moderate altitude acclimatization. Resting blood glucose determined in the mornings was relatively stable throughout the study ($P>0.05$). Of most importance for the current study, blood glucose values about 1 hr before the start of the long endurance performance tests in the HC and PP were nearly identical.

**Table 4. Resting Blood Values at Sea Level, and Before, During and After Staging**

| | SL | HC | STG2 | STG4 | STG6 | PP |
|---|---|---|---|---|---|---|
| **$P_aCO_2$ (Torr)** | 40.8 ± 1 | 38.0 ± 1* | 37.7 ± 1* | 36.4 ± 1* | | 32.4 ± 1*[,a] |
| **Hemoglobin (mg%)** | 14.7 ± 0.2 | 14.8 ± 0.3 | 14.7 ± 0.3 | | 15.0 ± 0.3 | 15.3 ± 0.3*[,a] |
| **Hematocrit (%)** | 43.1 ± 1 | 43.5 ± 1 | 43.3 ± 1 | | 44.0 ± 1 | 45.1 ± 1*[,a,b] |
| **PV reduction (%)** | | 1.3 ± 2 | 5.3 ± 1 | | 3.3 ± 2 | 7.4 ± 2[a] |
| **Glucose (mmol)** | 4.89 ± 0.2 | 5.37 ± 0.2 | 4.89 ± 0.1 | | 5.20 ± 0.1 | 5.36 ± 0.2 |

STGx = Day of staging at moderate altitude; *P<0.05 from SL; [a]P<0.05 from HC. [b]P<0.05 from STG2 and STG6. %PV reduction = %plasma volume reduction from SL based on Dill and Costill (6).

## ACUTE MOUNTAIN SICKNESS

The mean AMS-C score of the ESQ at SL was 0.06 ± 0.04, tended to rise on STG1 to 0.22 ± 0.12, but then progressively decreased from to 0.05 ± 0.03 by STG6. Similar results were obtained using the LLS: from 1.60 ± 0.80 on STG1 to 0 on STG6. On an individual basis, the ESQ determined that none of the volunteers had AMS, whereas the LLS determined that 4 volunteers had mild AMS on STG1, 3 on STG2, 2 on STG3, and none thereafter. These values indicate that, at worst, very slight AMS occurred during the first few days of moderate altitude acclimatization (primarily headache), and then only in a minority of the volunteers.

The mean group AMS-C score calculated from the ESQ indicated that there was also an absence of AMS at 4300 m prior to the start of exercise in both the HC (0.27 ± 0.11) and PP (0.31 ± 0.17). Similar group results were obtained using the LLS: 0.55 ± 0.31 in the HC and 0.64 ± 0.37 at PP. On an individual basis, the ESQ determined that one of the 10 volunteers had AMS in the HC (score = 1.094) and at PP (score = 1.649), and the LLS determined that the same volunteer had AMS (score = 3), but only at PP.

## LONG ENDURANCE PERFORMANCE

### Steady-State Exercise

Power outputs were intentionally reduced (P<0.01) from SL in the HC and at PP during low (116.0 ± 8 to 72.5 ± 5 w) and high (158.0 ± 7 to 116.0 ± 8 w) intensity SS exercise to maintain an equivalent altitude-specific $\%\dot{V}_{O_2peak}$ exercise intensities (at 45% and 65%, respectively) prior to the 720 kJ time trial. This was done so that the volunteers would begin each of the 720 kJ time trials after utilizing equivalent amounts of muscle glycogen during SS exercise (26). Moreover, since the wattage for the low and high intensity power outputs used in the HC and at PP were identical, the effect of 6 days of staging on HR, $SaO_2$, and RPE responses to SS exercise could be meaningfully assessed.

Table 5 shows the HR, $SaO_2$, and RPE responses to the identical low and high intensity SS exercise before (in the HC) and after (at PP) staging. Each of the measures was significantly improved or tended to improve from HC to PP for the low and high exercise intensity levels. The beneficial direction of the changes in exercise HR, $SaO_2$, and RPE are consistent with acclimatization acquired as a result of staging.

**Table 5. Steady-State Values at Low and High Exercise Intensities Before and After Staging**

| Exercise Intensity | Measurement | Hypobaric Chamber | Pikes Peak |
|---|---|---|---|
| | | | |
| **Low** | HR (b/min) | 122.8 ± 5 | 118.5 ± 4[a] |
| **(72.5 ± 14 W)** | $SaO_2$ (%) | 75.0 ± 2 | 77.2 ± 1* |
| **(~45% $\dot{V}O_{2peak}$)** | RPE | 8.4 ± 1 | 7.4 ± 1 |
| | | | |
| **High** | HR (b/min) | 147.8 ±5 | 140.1 ± 5* |
| **(116.0 ± 23 W)** | $SaO_2$ (%) | 75.6± 2 | 76.8 ± 1 |
| **(~65% $\dot{V}O_{2peak}$)** | RPE | 11.7 ± 1 | 9.2 ± 1* |

*P<0.01 Pikes Peak compared to hypobaric chamber.
[a]P =.068 Pikes Peak compared to hypobaric chamber.

**Time-Trial Performance (Table 6 and Figure 1)**

**Time-Trial Durations.** In the HC during USARIEM baseline phase, 2 volunteers were unable to complete the entire 720 kJ TT due to "altitude making my leg muscles too tired." One completed 59% of the 720 kJ (i.e., 423 kJ) and the other, 49% (i.e., 351 kJ). Both of these volunteers (as well as all others) were able to complete 720 kJ TT at SL and PP. In order to meaningfully compare TT results for these 2 volunteers, all their data collected at SL, HC, and PP were compared only up to 423 kJ and 351 kJ, respectively. Thus, for the entire group, the average TT completed in each phase was 653.4 ± 47 kJ.

Performance durations were 61.0 ± 17% longer in the HC and 26.0 ± 4% longer at PP compared with SL (73.2 ± 6 min). Also, performance time was improved for all 10 volunteers by an average of 19.5 ± 6 min (17.2 ± 6%) at PP (91.9 ± 6 min) compared to the HC (111.4 ± 6). Relative to SL, TT performance was impaired by 38.1 ± 6 min prior to staging and 18.7 ± 3 min after staging, indicating that acclimatization resulting from staging at moderate altitude eliminated 44.2 ± 8% of the initial TT deficit as measured in the HC.

**Power Output.** Mean power output used during the TT was lower in the HC and PP compared to SL, but was 20% higher at PP compared to HC. Power output expressed as %SL $W_{peak}$ also was similarly altered among test days. When mean power output was expressed as %AltSpec $W_{peak}$, only in HC was power output reduced from SL; after staging, the volunteers had improved such that they were able to exercise at a similar percentage of $W_{peak}$ as at SL.

**Oxygen Uptake.** The values for changes in $\dot{V}_{O_2}$ closely tracked the results for changes in watts used either expressed in absolute terms or as %SL $\dot{V}_{O_2 peak}$. That is, from SL to HC or PP, $\dot{V}_{O_2}$ values were reduced, but higher at PP than HC ($P<0.01$). When expressed as %AltSpec $\dot{V}_{O_2 peak}$ used during the TT, the reduction from SL occurred in the HC but not PP.

**Arterial Oxygen Saturation.** $SaO_2$ was reduced ($P<0.01$) from SL to HC. $SaO_2$ tended to increase at PP ($P>0.05$) compared to HC despite the TT being performed at a higher power output at PP. However, the individual changes in exercise $SaO_2$ during 45% and 65% $\dot{V}_{O_2 peak}$ and TT were directly related to the individual absolute or percentage improvements in TT performance from HC to PP (Figure 2). The close association between higher exercise $SaO_2$ and improved TT performance, as well as the changes in $P_{ET}CO_2$ and $P_{ET}O_2$, suggest ventilatory acclimatization was a major contributing factor for improved TT performance after staging. Hemoconcentration (as reflected by increases in hemoglobin concentration and hematocrit, or an increase in calculated plasma volume decrease, see above) was not significantly related to TT performance ($R \leq 0.33$, $P>0.05$).

**Ratings of Perceived Exertion.** RPE increased from SL to HC ($P<0.01$). Despite exercising at a power output that was approximately 20% higher at PP than HC, RPE was reduced ($P<0.01$) to the same level as at SL.

**Heart Rate.** Exercise HR and %SL $HR_{peak}$ were reduced from SL to HC and PP ($P<0.01$). Despite exercising at a higher power output at PP than in the HC, there was no increase in HR. When expressed as %AltSpec $HR_{peak}$, there were no differences among testing days.

**Figure 1. Effect of Staging on Time-Trial Performance**

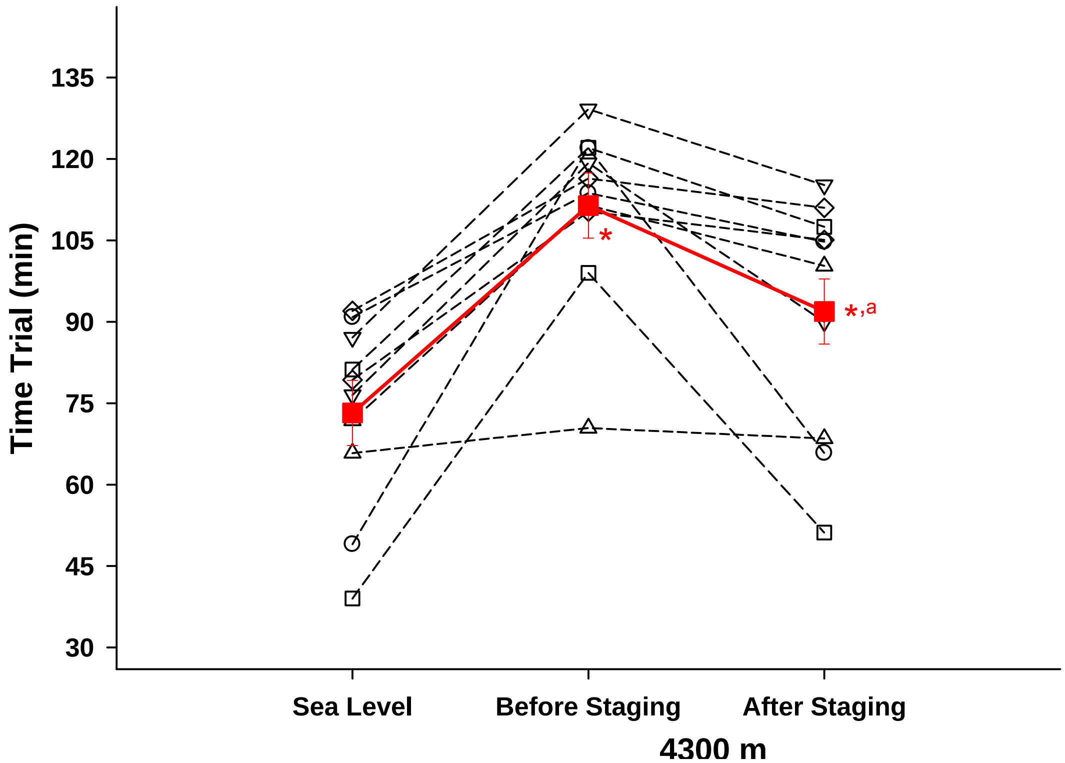


**Figure 2. Changes in TT Performance and Exercise $SaO_2$ from HC to PP**

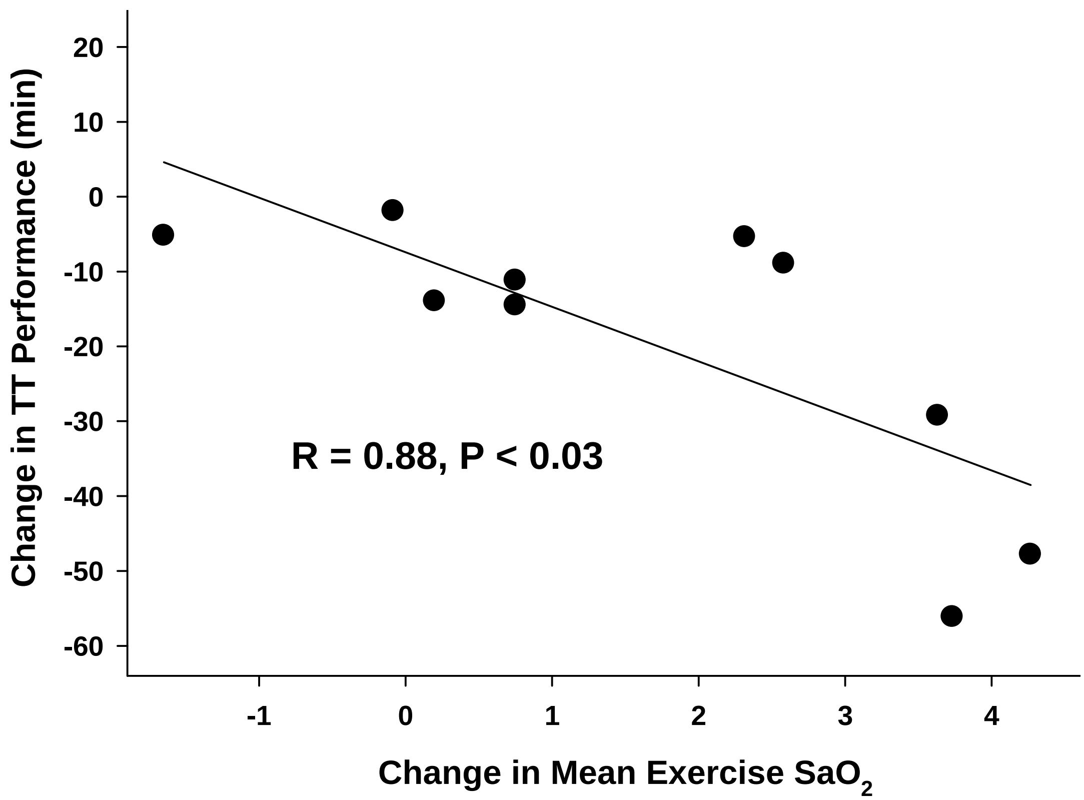

**Table 6. Time-Trial Values at Sea Level, and Before and After Staging**

| | Sea Level | Hypobaric Chamber | Pikes Peak |
|---|---|---|---|
| **TT Duration (min)** | 73.2 ± 6 | 111.4 ± 6* | 91.9 ± 7*[,a] |
| | | | |
| **Power Output (W)** | 150.0 ± 5 | 100.4 ± 10* | 120.2 ± 7*[,a] |
| **Power Output (%SL $W_{peak}$)** | 52.9 ± 2 | 37.9 ± 4* | 45.4 ± 3[b] |
| **Power Output (%AltSpec $W_{peak}$)** | 52.9 ± 2 | 42.7 ± 4* | 51.5 ± 2[a] |
| | | | |
| **$VO_2$ (ml/min)** | 2280 ± 147 | 1478 ± 167* | 1765 ± 131*[,a] |
| **$VO_2$ (%SL $\dot{V}_{O_2 peak}$)** | 59.2 ± 5 | 37.2 ± 3* | 45.3 ± 3*[,a] |
| **$VO_2$ (%AltSpec $\dot{V}_{O_2 peak}$)** | 59.2 ± 2 | 54.1 ± 5* | 65.7 ± 4[a] |
| | | | |
| **Arterial Oxygen Saturation (%)** | 96.5 ± 1 | 74.1 ± 1* | 75.7 ± 1* |
| | | | |
| **Ratings of Perceived Exertion** | 13.2 ± 1 | 15.5 ± 1* | 13.0 ± 1 |
| | | | |
| **Heart Rate (b/min)** | 160.3 ± 5 | 147.7 ± 6[c] | 148.4± 4[c] |
| **Heart Rate (%SL $HR_{peak}$)** | 85.4 ± 2 | 78.9 ± 3[c] | 79.1 ± 2[c] |
| **Heart Rate (%AltSpec $HR_{peak}$)** | 85.4 ± 2 | 81.2 ± 4 | 81.3 ± 2 |

Values are means ± SE; W = watts; $VO_2$ = oxygen uptake; %SL $W_{peak}$, %SL $VO_{2peak}$, %SL $HR_{peak}$ = percentage of $SL_{peak}$ values for watts, oxygen uptake, and heart rate, respectively, (as determined during the SL $VO_{2peak}$ test) that was used during the time trial; %AltSpec $W_{peak}$, %AltSpec $W_{peak}$, %AltSpec $HR_{peak}$ = percentage of altitude-specific peak values for watts, oxygen uptake, and heart rate, respectively, (as determined during SL or HC $VO_{2peak}$ test) that was used during the time trial; *P<0.01 from SL. [a]P<0.01 from hypobaric chamber; [b]P<0.04 from SL and hypobaric chamber; [c]P<0.05 from sea level.

## PERFORMANCE COMPARISONS TO OUR PREVIOUS STUDIES

One major objective of the current study was to determine if TT performance of previously unacclimatized SLR at 4300 m could be improved by staging for 6 days at a moderate altitude of 2200 m. The data of the current study unequivocally indicated that staging greatly improved high altitude TT performance at 4300 m. Another major objective was to determine just how effective staging actually was. The results from the current study were therefore compared to results of two related studies previously conducted by the same investigative team using many of the same procedures before and during exposure to high altitude (9; 11).

### Volunteer Baseline Characteristics

For each study, the number, sex, age, body weight, height, $\dot{V}_{O_2 peak}$, $W_{peak}$, and TT performance measured at their baseline residence (i.e., SL for Studies 1 and 3, and 2200 m for Study 2) are listed in Table 7. Only the data of those who completed all their scheduled 720 kJ TT were used so that the results among studies could be meaningfully compared.

Note the large peak and TT exercise performance differences in the volunteer baseline characteristics among the three studies. There were large differences in $\dot{V}_{O_2peak}$ values of the volunteers in Study 2 compared to those of the other two studies. Even when the $\dot{V}_{O_2peak}$ values of the volunteers in Study 2 were adjusted upwards by 10% (to 47 ml/min/kg and 3267 ml/min) to account for the altitude-induced reduction in $\dot{V}_{O_2peak}$ (10), the values were still considerably lower for $\dot{V}_{O_2peak}$ when compared to the volunteers in Studies 1 and 3.

It was not surprising that the volunteers in Study 1 completed the TT in the shortest amount of time since they had the highest $\dot{V}_{O_2peak}$ , $W_{peak}$, and most cycling experience compared to the other two groups of volunteers. However, it is interesting that the volunteers in Study 2 were able to complete the same 720 kJ TT in approximately the same time at 2200 m as the volunteers in Study 3 did at SL despite being older and of smaller stature, and having the lower values for $\dot{V}_{O_2peak}$ and $W_{peak}$. A seemingly disproportionate endurance performance for a given $\dot{V}_{O_2peak}$ is a common finding for acclimatized individuals, since endurance performance but not $VO_{2peak}$ is improved at altitude with acclimatization (10; 16).

**Table 7. Volunteer Characteristics for the Three Compared Studies**

| **VOLUNTEER CHARACTERISTICS:** | **STUDY 1: UnAcclimatized SLR[b]** | **STUDY 2: Acclimatized MAR[b]** | **STUDY 3: Staged SLR[b]** |
|---|---|---|---|
| N (sex) | 7 (all men) | 15 (9 men, 6 women) | 8 (all men) |
| Age (yrs) | 26 ± 2 | 30 ± 1[X,Y] | 21 ± 1[X] |
| Body Weight (kgs) | 78 ± 4 | 70 ± 3[Y] | 82 ± 5 |
| Height (cm) | 176 ± 2 | 175 ± 3 | 179 ± 3 |
| $VO_{2peak}$ (ml/min/kg) | 55 ± 2 | 42 ± 2[X,Y] | 50 ± 3 |
| Estimated Sea Level Baseline $VO_{2peak}$ (ml/min/kg) | n/a | 47 ± 2[X,Y] | n/a |
| $VO_{2peak}$ (ml/min) | 4276 ± 222 | 2940 ± 140[X,Y] | 4056 ± 236 |
| Estimated Sea Level Baseline $VO_{2peak}$ (ml/min) | n/a | 3267 ± 150[X,Y] | n/a |
| $W_{peak}$ | 349 ± 19 | 262 ± 14 | 290 ± 11 |
| TT Performance (min) | 62 ± 6 | 88 ± 3[X] | 81 ± 4[X] |

b = Baseline testing was performed either at sea level for Studies 1 and 3, or at 2200 m for Study 2.
[X]$P<0.05$ from Study 1; [Y]$P<0.05$ from Study 3.

**Effect of Altitude Acclimatization on Time-Trial Performance of Sea-Level Residents**

The first TT performance comparison made was between the altitude intervention results of Study 1 and the current study to determine the relative benefit for SLR of living for 10 days at 4300 m to living for 6 days at 2200 m on TT performance subsequently assessed at 4300 m. The TT durations during the first exposure to 4300 m in each study (i.e., day 3 for Study 1 and <5 hrs in the HC for Study 3) were similar (Table 8) despite a wide difference in TT durations at SL. After seven additional days of living at 4300 m, TT performance of the volunteers in Study 1 improved by ~11%, whereas after 6 days of living at 2200 m, the volunteers in Study 3 improved similarly (~10%). It should be noted that if the SLR volunteers of Study 1 were initially tested on the 1st day at 4300 m rather than the 3rd day, their TT performance may have been worse and therefore the improvement to day 10 would have been somewhat larger than 11%. Nevertheless, the results of the current study suggest that staging at moderate altitude was quite effective compared to living for 10 days at 4300 m on TT performance at 4300 m.

**Table 8. Time-Trial Performances of Sea-Level Residents at 4300 m Before and After Acclimatization**

| TIME-TRIAL PERFORMANCE: | STUDY 1: UnAcclimatized SLR | STUDY 3: Staged SLR |
|---|---|---|
| Pre-intervention, at 4300 m (min) | 104.6 ± 11* | 111.6 ± 7* |
| Post-intervention, at 4300 m (min) | 91.4 ± 7** | 100.3 ± 6** |
| Change in TT duration (min)[a] | 13.2 ± 6 | 11.3 ± 3 |
| Change in TT duration (%)[a] | 10.8 ± 4 | 9.7 ± 3 |

Baseline testing was performed at sea level for both studies. *P<0.05 from sea level; **P<0.05 from initial TT performance at 4300 m; a = change in duration of TT before and after acclimatization strategy (from days 3 to 10 at 4300 m for Study 1, and from HC to PP1 after 6 days at 2200 m for Study 2).

**Comparison of Acclimatized Sea-Level Residents and Moderate Altitude Residents**

It was clear SLRs who lived for 6 days at 2200 m greatly improved TT performance on subsequent exposure to 4300 m, with the improvement being comparable to those who had lived for 10 days only at 4300 m. The next step was to compare the relative effectiveness of living at moderate altitude for short and long periods of time on TT performance during subsequent exposure to 4300 m. This was attempted by comparing the TT performance results at 4300 m of the SLR from Studies 1 and 3 to the results collected from MAR exposed to 4300 m who were fully acclimatized to moderate altitude (11).

However, the large unanticipated differences in volunteer characteristics and exercise capabilities, as well as the difference in baseline testing elevations among studies outlined above, made direct study to study comparisons of absolute values for exercise performance and physiological changes during the TT difficult. To overcome some of these problems, objective comparisons within and among studies were made using indices of exercise intensity that were common and normalized to fitness for all studies. The various indices of exercise intensity used during the TT were calculated and compared for all three studies at the resident baseline altitude, and before and after the respective acclimatization intervention. The rational used took advantage of the TT performance paradigm and our previous experience (9; 11). That is, [1] a change in exercise intensity is inversely associated with a change in TT duration, and [2] level of acclimatization is directly associated with exercise intensity. Thus, it follows that the more acclimatization acquired, the higher the exercise intensity capability, and the faster the TT would be completed. The indices compared were the percentages of the $\dot{V}_{O_2 peak}$ and $W_{peak}$ determined at the resident altitude (i.e., sea level or 2200 m baseline), as well as the $\dot{V}_{O_2 peak}$ and $W_{peak}$ determined at the same altitude as the TT (i.e., SL, 2200 m, or 4300 m; "altitude specific").

Despite the large differences in physical characteristics, exercise capabilities, and baseline testing elevations, the volunteers from all three studies exercised at remarkably similar exercise intensities during their TTs at their baseline elevation (Table 9). However, during initial exposure to 4300 m ("pre-intervention"), when there was little (Study 1) or no (Study 3) altitude acclimatization for the SLR, there were large and similar reductions in exercise intensity expressed as %Baseline $W_{peak}$ or %Baseline $\dot{V}_{O_2 peak}$ . In contrast, there was a much smaller decline in %Baseline $W_{peak}$ and no decline in %Baseline $\dot{V}_{O_2 peak}$ for the MAR during day 1 of their exposure to 4300 m.

After their respective acclimatization interventions ("post-intervention"), SLR exercise intensities became higher at 4300 m. However, their levels of exercise intensity were never higher than that of the MAR. In fact, %Baseline $\dot{V}_{O_2 peak}$ and %Baseline $W_{peak}$ of the MAR on day 1 of their exposure to 4300 m were as high or higher than the levels obtained at 4300 m for SLR either after having lived for 10 days at 4300 m (Study 1) or for 6 days at 2200 m (Study 3).

As expected, exercise $SaO_2$ during the baseline TT was lower for the MAR at 2200 m than for the SLR at sea level. However, during the first day of exposure to 4300 m, the $SaO_2$ of the MAR was higher (79%) than the SLR in Studies 1 (day 3: 74%) and 3 (day 1: 75%). It then took 10 days of living at 4300 m for the exercise $SaO_2$ of the SLR in Study 1 (81%) to be similar to that of the MAR. Moreover, despite the similarity in TT $SaO_2$, the MAR were still able to exercise at a higher %Baseline $\dot{V}_{O_2 peak}$ and $W_{peak}$ than the SLR. In contrast, there was no increase in TT $SaO_2$ at 4300 m for the SLR of Study 3 that resulted from 6 days of staging at 2200m.

**Table 9. Among Studies Comparisons of Exercise Intensity and Arterial Oxygen Saturation**

| | STUDY 1: UnAcclimatized SLR | STUDY 2: Acclimatized MAR | STUDY 3: Staged SLR |
|---|---|---|---|
| **1. TT EXERCISE INTENSITY (%Baseline $W_{peak}$):** | | | |
| Baseline | 57 ± 4 | 54 ± 2 | 52 ± 2 |
| Pre-intervention, at 4300 m | 35 ± 2* | | 38 ± 2* |
| Post-intervention, at 4300 m | 38 ± 1* | 46 ± 2*,X | 42 ± 2* |
| | | | |
| **2. TT EXERCISE INTENSITY (%Altitude Specific $W_{peak}$):** | | | |
| Baseline | 57 ± 4 | 54 ± 3 | 52 ± 2 |
| Pre-intervention, at 4300 m | 47 ± 3* | | 47 ± 3* |
| Post-intervention, at 4300 m | 56 ± 4** | 53 ± 2 | 50 ± 3** |
| | | | |
| **3. TT EXERCISE INTENSITY (%Baseline $\dot{V}_{O_2 peak}$):** | | | |
| Baseline | 62 ± 5 | 59 ± 3 | 58 ± 6 |
| Pre-intervention, at 4300 m | 43 ± 3* | | 41 ± 3* |
| Post-intervention, at 4300 m | 48 ± 3*,** | 56 ± 2X,Y | 48 ± 3*,** |
| | | | |
| **4. TT EXERCISE INTENSITY (%Altitude Specific $\dot{V}_{O_2 peak}$):** | | | |
| Baseline | 62 ± 5 | 60 ± 3 | 58 ± 6 |
| Pre-intervention, at 4300 m | 59 ± 4 | | 59 ± 4 |
| Post-intervention, at 4300 m | 66 ± 4** | 65 ± 2* | 69 ± 4** |
| | | | |
| **5. TT $SaO_2$ (%):** | | | |
| Baseline | 96 ± 1 | 92 ± 1X,Y | 97 ± 1 |
| Pre-intervention, at 4300 m | 74 ± 2* | | 75 ± 2* |
| Post-intervention, at 4300 m | 81 ± 1*,** | 79 ± 1*,X,Y | 76 ± 2* |

Baseline testing was performed at sea level (Studies 1 and 3) or 2200 m (Study 2). %Baseline $W_{peak}$ = Percentage of peak power output (watts) that was determined at baseline (SL or 2200 m). %Altitude Specific $W_{peak}$ = percentage of peak power output (watts) that was determined at the same altitude as the TT. %Baseline $VO_{2peak}$ = Percentage of $VO_{2peak}$ that was determined at baseline (SL or 2200 m). %Altitude Specific $VO_{2peak}$ = percentage of $VO_{2peak}$ that was determined at the same altitude as the TT. ). Pre-intervention, at 4300m = TT exercise intensity at 4300 m before little (Study 1) or no (Study 3) altitude acclimatization; Post-intervention, at 4300 m = TT intensity at 4300 m after 10 days of 4300 m acclimatization (Study 1), or 2 years (Study 2) or 6 days (Study 3) of moderate altitude acclimatization. *P<0.05 from baseline; **P<0.05 from pre-intervention TT performance at 4300 m; [X]P<0.05 from Study 1; [Y]P<0.05 from Study 3.

## DISCUSSION

Staging for several days at a moderate altitude prior to ascending to a higher altitude is a time-honored acclimatization strategy (7; 14; 19). The primary criterion that has been used to determine the effectiveness of staging is the reduction in AMS symptoms at the higher elevation (5; 14). Depending on factors such as the staging elevation and the duration of the staging sojourn, the reported effectiveness of staging for reducing AMS symptoms has ranged from 20% to 85% (7; 15; 25; 29). To our knowledge, the effect of staging on endurance performance has not been previously reported. The present study was the first, therefore, to present a quantitative and systematic appraisal of the effect of staging at a moderate altitude on endurance performance at the higher elevation.

Our results clearly indicate that 6 days of staging at a moderate altitude of 2200 m enhanced TT performance of all 10 sea-level residents by an average of 17% during exposure to 4300 m. Compared to the TT duration at sea level (i.e., 73 min), the TT at 4300 m took 38 min longer to complete before staging (to 111 min), but only 19 min longer after staging (to 92 min). This finding shows that acclimatization resulting from only 6 days of staging at 2200 m eliminated nearly half of the initial TT impairment at 4300 m (range: 17% to 80%). There were also very mild AMS symptoms reported during the staging phase. It is also important to note that the TT performance results were not confounded by differences in AMS severity and incidence from before to after staging at 4300 m. Collectively, these findings indicate that the staging elevation and duration combination used provided a highly effective means for attenuating the large physical performance decrement during initial exposure to 4300 m.

Residence at a given altitude induces a variety of physiological adjustments characteristic of altitude acclimatization that occur to minimize the impact of hypoxemia and that are generally proportional to the altitude and time spent at that elevation (4; 13; 30). In the current study, traditional ventilatory and blood markers of acclimatization such as $P_{ET}CO_2$ or $P_aCO_2$, $P_{ET}O_2$, $SaO_2$ and [Hb] (30) were monitored at rest or during standardized exercise before, during, and after 6 days of staging at 2200 m. The $P_{ET}CO_2$ and $P_aCO_2$ reductions, $P_{ET}O_2$ and $SaO_2$ increases, and hemoconcentration observed either while living at 2200 m, or in response to 4300 m after staging, indicate that at least partial acclimatization occurred while living at moderate altitude (4; 17). Evidence of the benefit of moderate altitude acclimatization for exercise at 4300 m were manifested as generally lower RPE and HR and higher $SaO_2$ for the same (i.e., steady-state) or higher (i.e., TT) power output after staging compared to before staging. There was also, as expected, a reduction in AMS after staging (1)

Ventilatory acclimatization and hemoconcentration help raise arterial oxygen content which, in turn, facilitates oxygen transport and delivery to metabolic active tissues (18). The higher association between improved TT performance and changes in exercise $SaO_2$ ($R = 0.88$, $P<0.03$), rather than a change in [Hb] resulting from plasma volume loss ($R < 0.33$, $P$ = ns) suggest that ventilatory acclimatization was the more beneficial factor resulting from staging, as has been previously proposed for relatively short exposures to altitude (28; 30). Ventilatory acclimatization also has been implicated as a major factor responsible for the much lower incidence and severity of AMS at 4300 m for both acclimatized SLR (1) and MAR (20) compared to unacclimatized SLR.

An interesting finding was the similarity of improvement in TT performance at 4300 m despite a considerable difference in the acclimatization “profile” for the SLR who had lived at 4300 m for 10 days compared to those who were staged at 2200 m for 6 days. For example, TT $SaO_2$ increased from 74% to 81% during 10 days of living at 4300 m, whereas TT $SaO_2$ was nearly the same at 4300 m before and after staging (at ~76%). Exertion during the TT for the SLR after acclimatization to 4300 m was perceived to be greater compared to the SLR who were staged (RPE: 15 versus 13) despite a lower average heart rate (134 b/min versus 148 b/min). There was also a large difference in plasma volume reduction between the SLR after 4300 m (~20%, (9)) and the SLR who were staged (~7%). Despite physiological differences among the acclimatization strategies, there is no question that the living for several days at either 2200 m or 4300 m improves TT performance at 4300 m.

It is also noteworthy that the MAR responded better than the two SLR groups when exposed to 4300 m. Whereas the two SLR groups had large reductions in the various measures of exercise intensity with initial exposure to 4300 m, the MAR had little or no reduction in any of the measures. The exercise intensity values for the MAR on their first day of exposure to 4300 m were high as or higher than either of the two SLR groups after they had undergone their respective acclimatization interventions. Even though TT performance durations could not be directly compared among studies, the MAR were able to perform at a higher exercise intensity while maintaining a higher $SaO_2$ during the TT at 4300 m. Thus, it is tempting to speculate that if the groups were of similar physical fitness (e.g., similar $\dot{V}_{O_2 peak}$ and $W_{peak}$), the MAR likely would have completed the TT on their initial exposure to 4300 m in less time than the SLR were able to do even after the SLR underwent their respective acclimatization interventions. This conclusion is consistent with a previous analysis (11) indicating that initial TT performance at 4300 m of similarly partially acclimatized SLR would be ~50% less than that of MAR.

In summary, staging of previously unacclimatized SLR at a moderate elevation of 2200 m for 6 days greatly improved prolonged TT performance during subsequent exposure to 4300 m. Time-trial performance improvement from before to after staging was directly related to ventilatory acclimatization acquired during staging. While the magnitude of improvement in TT performance at 4300 m for those who were staged at moderate altitude was similar to that acquired by living for 10 days at 4300 m, the acquired physiological “profile” differed greatly between the two acclimatization strategies. However, even after acclimatization, the improved TT performances of both groups of SLR were not likely to be as good as the TT performance of the MAR on their first day of exposure to 4300 m.

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